

# CARDIAC FUNCTION ESTIMATION FOR RESYNCHRONIZATION THERAPY: COMPARISON BETWEEN MULTISLICE-CT AND SPECKLE TRACKING IMAGING

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## ABSTRACT

New tools for the assessment of intra-ventricular dyssynchrony can enable the optimization of Bi-ventricular Cardiac Resynchronization Therapy. Multislice-CT (MSCT) imaging may be a good complement to ultrasound (US) imaging modalities. Moreover, its potential to get a functional and anatomical description of the heart within a single exam constitutes a motivation for this work. This paper is focused on the comparison of motion descriptive features estimated from two modalities: MSCT and Speckle Tracking Imaging (STI). The method of motion estimation in MSCT imaging that we have proposed is applied and allows to decompose motion in its main components. These motion components have been compared with those provided by STI. First results obtained on two patients databases are shown and discussed. A first qualitative evaluation shows how MSCT is powerful, providing the means to characterize dyssynchrony in 3D.

**Index Terms**— Cardiac function, Multislice-CT, Speckle tracking imaging, Mechanical dyssynchrony, Cardiac Resynchronization Therapy.

## 1. INTRODUCTION

Nowadays, Cardiac Resynchronization Therapy (CRT) is accepted as a therapeutic option in heart failure patients who remain highly symptomatic despite optimized medical treatment [1]. However, one third of the patients do not respond to the therapy [2]. Therefore, imaging modalities including echocardiography or Magnetic Resonance Imaging methods, aimed at mechanical dyssynchrony estimation, have been recently proposed to improve patient selection criteria and lead placement [3, 4]. The most challenging task to carry out remains both the identification of the most effective pacing sites and the left ventricular lead positioning. This work is part of the IMOP project (IMaging for Optimisation of biventricular Pacing) which purpose is to

define a CRT optimization method based on the fusion of mechanical, electrical and anatomical data. Our objective is to better plan the placement of CRT leads using the new Multislice-CT (MSCT) capabilities in imaging the heart. This modality provides the means to analyse both venous anatomical structures and left ventricle function in only one exam. With this modality, transvenous path finding methods and motion estimation approaches have been previously proposed [5, 6].

This paper is focused on the comparison of cardiac motion descriptors issued from two modalities: MSCT and Speckle Tracking Imaging (STI). It is organized as follows: first, the cardiac motion estimation method that we have proposed and applied to MSCT imaging is resumed. Speckle Tracking Imaging is then introduced. The method of comparison that we have developed is then described. First results obtained on two patient databases are presented and discussed in a qualitative way, and followed by some conclusions.

## 2. METHOD

### 2.1. Cardiac motion estimation in Multislice-CT

CT imaging is useful for the 3D visualization of coronary vessels (arteries and veins). Technical improvements in CT imaging have led to the introduction of Multi-Slice CT, combining multi-detector and gantry high rotation speed. This generation of CT allows dynamic cardiac acquisition with a high spatial resolution.

The method we have previously proposed [6, 7] for cardiac function estimation relies on three steps:

- Segmentation of the left endocardium along the whole temporal sequence;
- Reconstruction of surface meshes corresponding to the segmented surfaces;
- Temporal surface matching to estimate the displacements of the mesh nodes.

The segmentation process is based on a region growing process bounded by gradient information. Its results have

been visually validated by a medical expert. The segmented surfaces are then reconstructed using the Marching Cubes algorithm.

The motion estimation relies on the multi-resolution matching of each pair of surfaces ( $S_1$ ,  $S_2$ ) corresponding to two following moments. It is based on a Markov Random Field representation, whose sites are the nodes of  $S_1$  and labels are the nodes of  $S_2$  which are estimated in correspondence. The minimization of a global energy led to the estimated motion field. The matching is guided by mean and Gaussian curvature information. In order to take advantage of the spatiotemporal regularity of the motion field, energy terms privileging low amplitude and spatially regular displacements are considered.

A multi-resolution scheme is used in order to optimize the minimization process. At the lowest resolution, the energy minimization is performed using a simulated annealing while, at higher resolutions, an iterated conditional mode (ICM) algorithm is used.

The application of this method to each pair of successive surfaces  $S_1$  and  $S_2$  results to one motion field associated to one instant of the cardiac cycle and defined on the set of nodes of the corresponding endocardial mesh.

## 2.2. Cardiac motion estimation and characterization by 2D speckle tracking

Speckle tracking is an image processing method that enables to assess cardiac motion from 2D dynamic echocardiographic images [8]. Routine B-mode grayscale images are analyzed for frame-by-frame movement of stable patterns of natural acoustic markers, or speckles, present in ultrasound tissue images over the cardiac cycle. The tracking relies on the manual selection of the endocardium contour. It is then extended to consider the whole myocardium and decomposed in segments (about 60 in long-axis view, 40 in short-axis view). Speckle tracking enables to track these segments and therefore to estimate cardiac motion.

In order to study precisely the extracted motion, it is decomposed, for each segment, in different components used in clinical routine, i.e. transverse and longitudinal components in long-axis view and radial component in short-axis view. Finally, a baseline correction is applied to each motion component in order to correct global displacement caused by patient breathing or probe displacement.

## 2.3. Comparison of extracted motions

Speckle tracking imaging, based on 2D dynamic echographic acquisitions, provides 2D displacements while MSCT provides 3D displacements associated to the whole endocardial surface. Therefore, in order to compare the cardiac function estimated in these two modalities, a

registration stage is required. This registration stage is based on four steps:

- Selection of the echographic plane in the CT data and extraction of the corresponding points and their associated motion;
- Temporal interpolation of the extracted CT motion;
- Spatial registration of the CT and US contours;
- Association, to each US data point, of the corresponding CT point.

These four steps are described in the following subsections.

### 2.3.1. Selection of the echographic plane in the CT data

The selection of the plane associated to the echographic acquisition in the CT data is realized manually. It relies on the selection of three points, selected on the first reconstructed endocardial surface. This selection is made according to ventricular apex, mitral valve, and papillary muscles.

Once the plane has been selected, it is used to cut through the reconstructed surface to generate a contour corresponding to the echographic plane. For each point of this contour, the neighbouring nodes (nodes located into a sphere centred on the point and with a radius of about 1.5mm) in the original surface mesh are selected and tracked according to their estimated motion.

Like for US data, displacements are decomposed according to the echographic plane. Finally, displacements associated to neighbouring nodes are averaged.

### 2.3.2. Temporal interpolation and baseline correction of the extracted CT motion

In order to obtain the same temporal resolution between CT and US data, a cubic spline interpolation is applied in the temporal sequence to each motion component and for each point of the CT contour.

Similarly to US data, a baseline correction is applied to displacements estimated from CT data, considering that each point returns to its initial position at the end of the cycle.

### 2.3.3. Spatial registration of CT and US contours

A rigid registration process is used to align CT and US extracted contours. Firstly, an ICP (Iterative Closest Point) algorithm associating rotation and translation is applied to the CT contour. Because the spatial resolution of CT is higher than US resolution, a scaling factor is applied (initialized at 1 and iteratively decreased until the sum of the squared Euclidian distances between nearest points stops decreasing). Finally, a second ICP is applied to refine the alignment.

### 2.3.4. Association between CT and US data points

Because the CT spatial resolution is higher than the US one, each US data point is associated to several CT data points. Therefore, for each US data point, the nearest CT data point are selected and their motion components averaged. After these four steps, we obtain one set of points (corresponding to the US data points) and, for each point, motion components estimated from CT and US data.

In order to display these motion components in a common way, we used a classic US representation (Fig. 1). It is based on the path followed from the base of the septal wall to the base of the anterior wall. For each point, the amplitude of the motion component is displayed according to time. It results to spatiotemporal maps used by physicians to detect intraventricular delays.

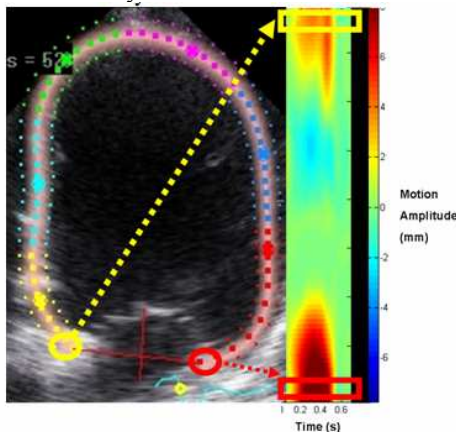


Fig. 1: Representation mode used to display motion components.

### 3. RESULTS

US and CT data used for this study have been acquired on the two first patients of the IMOP project that will finally include eight patients.

CT data acquisition has been realised with a 64-slices General Electric Lightspeed VCT 64 (GE, Milwaukee, WI, USA), providing 20 3D volumes (resolution: 0.3x0.3x0.5 mm) representing a whole cardiac cycle.

Transthoracic echocardiography has been performed using a GE Vivid 7 system equipped with a 2.5-MHz phased-array transducer. Two acquisitions have been realised in apical (long axis) view (4 and 2-chambers views) and three in parasternal short-axis views (basal left ventricle (LV), mid-LV and apical-LV). Images were acquired in 2D grayscale during one cardiac cycle. The frame rate is greater than 65 fr/s. Using the original images, measurements of myocardial displacements were performed offline in the longitudinal, transverse and radial axes, using a dedicated software package (GE Echopac).

The comparisons of the estimated displacements are given, at this time, in a qualitative way. Motion estimated from long axis data is illustrated by figures 2, 3 and 4. Figures 2 and 3 represent, respectively, longitudinal and transverse displacements estimated from 4-chambers acquisitions of the

2 patients. Figure 4 shows longitudinal and transverse displacements from 2-chambers acquisition of the first patient.

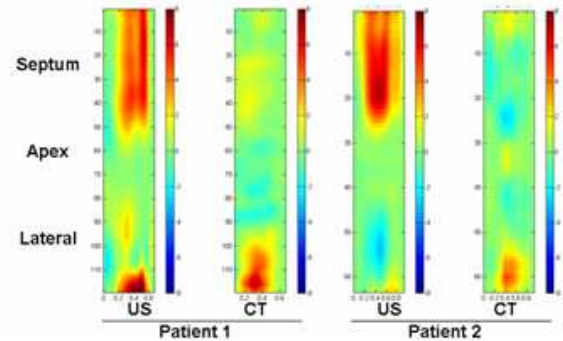


Fig. 2: Longitudinal displacement from apical 4-chamber view (patients 1 and 2).

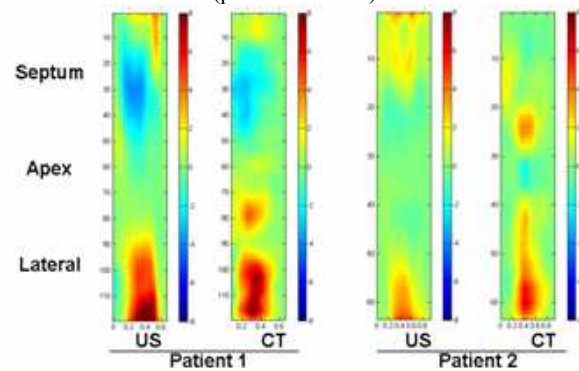


Fig. 3: Transverse displacement from apical 4-chamber view (patients 1 and 2).

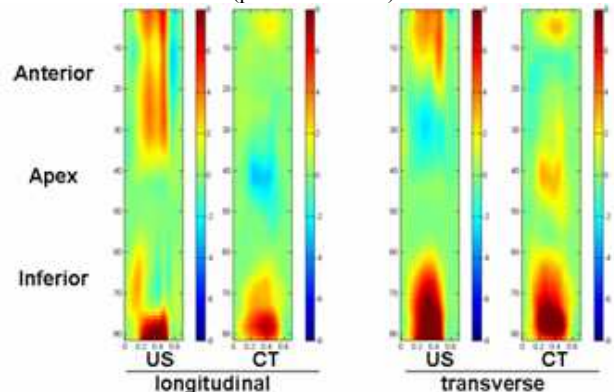


Fig. 4: Longitudinal and transverse displacements from apical 2-chamber view (patient 1).

These figures show that longitudinal components significantly differ between CT and US, especially in the septal segments. For transverse displacements, results are better, especially in the septal and lateral segments. However, transverse motion estimated in the apical segment show important differences. In the segments with good displacements coherence, a temporal delay appears: CT data seems to have an advance of about 100 ms.

Results obtained on 2-chamber acquisition confirm those obtained on 4-chamber data: longitudinal motion shows very

important differences, especially in the anterior segments while transverse displacements highlights an important coherence, excepting in the apical segment. Figure 5 represents radial component estimated from short axis data. The coherence of the estimation of this component with CT and US is satisfying, even if the delay previously exposed remains.

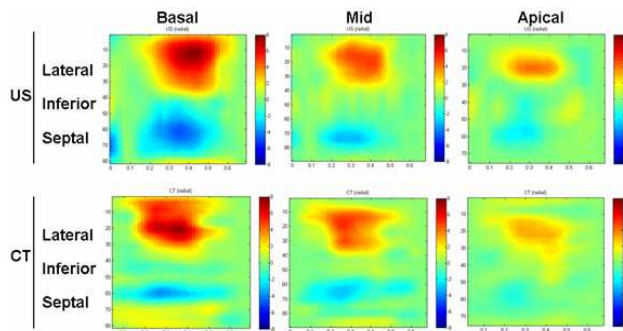


Fig. 5: Radial displacement from short-axis view (patient 1).

#### 4. INTERPRETATION

Results vary greatly according to the represented motion component: transverse and radial displacements show an important coherence while longitudinal displacements differ significantly.

The coherence shown in transverse and especially radial components is very satisfying because it has been proved that radial component study is the most useful motion component for dyssynchrony characterization [9].

The differences obtained with longitudinal component estimation are explained by the well-known aperture phenomenon. It highlights a more difficult estimation of motion components parallel to the considered surface, which is the case of the longitudinal motion in the basal and medial segments of the left ventricle.

The results also highlight the estimation incoherence in the apical segment. This can be explained by another well-known problem: the difficulty to visualize the apical area in echography.

The last result is the temporal advance shown by US estimated motion. This is caused by the difference in the mode of ECG synchronization: US acquisition starts at the beginning of the QRS complex, while CT acquisition is synchronized on the QRS peak. This results to a temporal difference of about 50 to 100 ms that can be noticed on the spatiotemporal maps.

#### 5. CONCLUSION AND PERSPECTIVES

Cardiac resynchronization therapy needs powerful tools to characterize intra-ventricular dyssynchrony in three dimensions. We have previously proposed a method for such a purpose from MSCT data. In this paper, we propose an

approach to compare displacements obtained with this method to displacements obtained with US speckle tracking method. In order to follow clinical routine, displacements are decomposed in different components before being compared. Results show a good similitude in transverse and especially in radial displacements while longitudinal components do not show a good coherence (explained by the aperture phenomenon). Therefore, this study shows very promising results for the characterization of ventricular contraction delays from MSCT imaging. Moreover, new MSCT generation will provide data with better temporal resolution allowing more precise motion estimation. Because MSCT is also useful for the extraction of the venous system (which is of primary importance for the implantation procedure), it opens the perspective of a functional and anatomical description of the heart within a single exam. Future works will lay on the search for 3D dyssynchrony descriptors from MSCT and on the fusion of these descriptors with venous and myocardial anatomical information.

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#### 6. REFERENCES

- [1] Leclercq, C., Kass, D.A., "Re-timing the failing heart: principles and current clinical status of cardiac resynchronization", *J.Am.Coll.Cardiol.*, 39, 194-201, 2002.
- [2] Mehra, M.R., Greenberg, B.H., "Cardiac resynchronization therapy: caveat medicus!", *J.Am.Coll.Cardiol.*, 43:1145-1148, 2004.
- [3] Bax, J.J., Abraham, T., Barold, S.S. et al., "Cardiac resynchronization therapy: Part 1, issues before device implantation", *J.Am.Col.Cardiol.*, 46:2153-2167, 2005.
- [4] Bank, A.J., Kelly, A.S., "Tissue Doppler imaging and left ventricular dyssynchrony in heart failure", *J.Card.Failure*, 12:154-162, 2006.
- [5] Coatrieux, J.L., Hernandez, A.I., Mabo, P., Garreau, M., Haigron, P., "Transvenous path finding in cardiac resynchronization therapy", *FIMH*, p.236-45, 2005.
- [6] Garreau, M., Simon, A., Boulmier, D., Coatrieux, J.L., Le Breton, H., "Surface and motion extraction in cardiac MSCT imaging for the assessment of left ventricular function", *International Journal of Biomedical Imaging*, Article ID 37607, 2006.
- [7] Simon, A., Garreau, M., Boulmier, D., Coatrieux, J.L., Le Breton, H., "Cardiac Motion Extraction Using 3D Surface Matching in Multislice Computed Tomography", *Medical Image Computing and Computer-Assisted Intervention*, 057-1059, 2004.
- [8] Langeland, S., et al., "Comparison of time-domain displacement estimators for two-dimensional RF tracking", *Ultrasound Med Biol*, 29(8): p. 1177-86, 2003.
- [9] Suffoletto, M.S., et al., "Novel speckle-tracking radial strain from routine black-and-white echocardiographic images to quantify dyssynchrony and predict response to cardiac resynchronization therapy", *Circulation*, 113(7): p. 960-8, 2006.